CHESTER

The Selection of Pumping Machinery for Water Supply

Mechanical Engineer

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THE SELECTION OF PUMPING MACHINERY FOR WATER SUPPLY

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BY

JOHN NEEDELS CHESTER

B. S. UNIVERSITY OF ILLINOIS, 1891
C. E. UNIVERSITY OF ILLINOIS, 1909

THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE

DEGREE OF

MECHANICAL ENGINEER

IN

THE GRADUATE SCHOOL

OF THE

UNIVERSITY OF ILLINOIS

1911

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UNIVERSITY OF ILLINOIS

THE GRADUATE SCHOOL

June 2, 1911

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

JOHN NEEDELS CHESTER

ENTITLED THE SELECTION OF PUMPING MACHINERY FOR

WATER SUPPLY

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Mechanical Engineer

In Charge of Major Work

G. G. Goodenough

Head of Department

Recommendation concurred in:

Edward C. Schmidt

Ernst J. Berg

G. G. Goodenough

Committee on Final Examination

197579

T H E S I S

The Selection of Pumping Machinery for Water Supply.

Submitted for the

Professional Degree

of

Mechanical Engineer

by

John Needels Chester, B.S.'91, C.E.'09. ME

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The engineer upon whom devolves the selection and operation of pumping machinery finds four distinct services for which he must provide.

(1) Deep Well or beyond suction;

(2) Low Service or to settling basins;

(3) General Service;

(4) Service higher than general, or booster.

DEEP WELL OR BEYOND SUCTION

The Deep Well or beyond suction is a type most annoying on account of unreliability and the high cost of repairs, its low state of development, and consequent low efficiency, and the high coal bills.

The machinery for this service may be subdivided as follows:

(a) Steam driven, direct acting, Deep Well Pumps;

(b) Power driven, direct acting, Deep Well Pumps;

(c) Air Lifts;

(d) Impeller or Deep Well Rotary Pumps.

(a) From the standpoint of economy the steam driven, deep well pump is seldom considered except in cases where but a small quantity from but few wells located near the boiler is desired. The steam consumption of this type seldom falls below 130 pounds per pump horse power per hour, and we have frequently found them consuming as high as 200 pounds per pump horse power per hour. The duty therefore ranges from 15,000,000 down to 10,000,000 foot

pounds of work per thousand pounds of dry steam consumed.

The following table will serve as an approximation of what on the basis of the few tests we have made may reasonably be expected from this type in pounds of steam per pump horse power per hour operating at builders' rated capacity, of course any speed less than this or any location in excess of 50 feet from boiler would increase the steam consumption materially:

Diameter of Well.	Depth of Working Barrel.								
	30'	40'	50'	60'	70'	80'	90'	100'	110'
3"	200	195	190	185	180	175	170	165	160
4"	195	190	185	180	175	170	165	160	155
5"	190	185	180	175	170	165	160	155	150
6"	185	180	175	170	165	160	155	150	145
8"	180	175	170	165	160	155	150	145	140
10"	175	170	165	160	155	150	145	140	135
12"	170	165	160	155	150	145	140	135	130

Beyond a lift of 100 feet the sucker rod troubles practically prohibit the use of this type.

The details of this pump are illustrated in Fig. 1. and while it is a type that has been on the market for years with but little improvements, the frequent necessity of withdrawing for repair the pump barrel has alone condemned it to many users.

It will be noted from the working parts of this machine that the pump is single acting but the differential plunger provided at the top of the well or surface of the ground with the aid of an air-chamber makes the discharge constant or the same as though the pump were double acting.

Fig. 2. illustrates a double acting working barrel or pump end which without the differential plunger at the top gives in connection with the air-chamber a fairly constant discharge. It also increases the capacity over the single acting but the complication of its parts stand against it with the consequence that a much larger percentage of steam driven deep well pumps are of the single acting type.

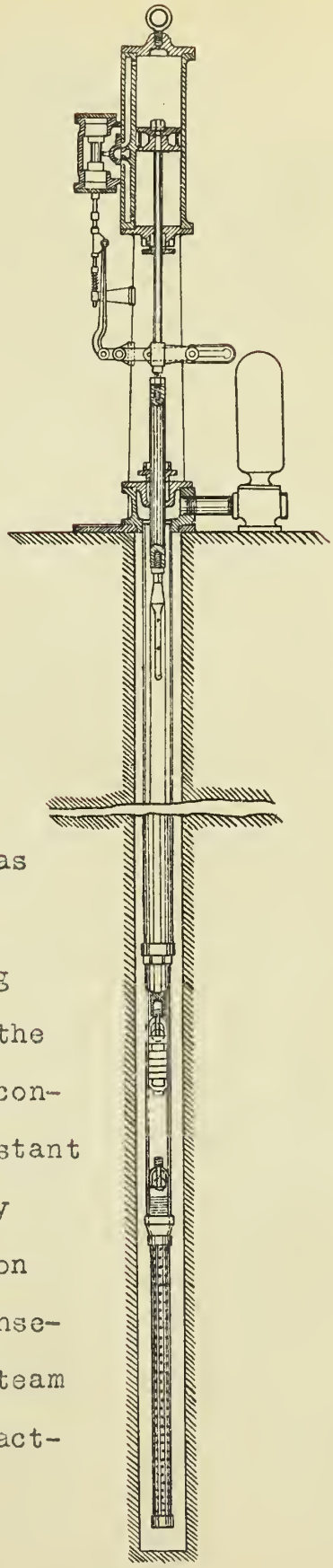


Fig. 1.

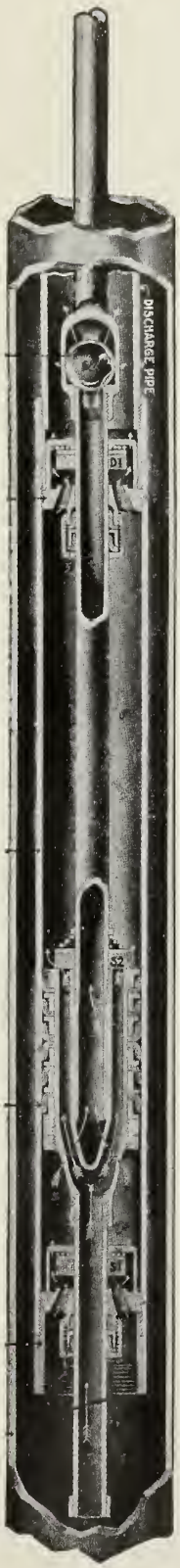


Fig. 2.

(b) POWER DRIVEN. When the number of wells and the necessary distance at which they must be put down from the steam plant warrants, a saving, depending in amount upon the number of wells and the horse power required to operate, can be made by substituting for the steam drive above discussed an electrically driven power head, and while the mechanical efficiency of the machine is then lowered, the heavier loss of transmitting steam long distances is reduced to the wire losses of electrical current and the excessive steam consumption of the steam driven type is greatly reduced by the substitution of a more economical steam motor employed in the generation of the necessary current. Fig. 3. illustrates in general this machine. A vast variation may be made in the economy of the steam motor and the efficiency of the pump but the following table will give the steam consumption that may be expected under different conditions:

Steam Consumption per Pump Horse-power-hour of Electrically Driven Deep Well Pumps. Engine efficiency assumed to be 85%; Generation 90%; Line drop 5%; and Motor efficiency 90%.

Lift in Feet.	Efficiency of Power Head & Pump.	Steam Consumption in pounds per I.H.P.-Hr. of Generator Engine.					
		15	20	25	30	35	40
30	40%	54.5	72.6	91.0	108.8	127	145
75	50%	43.6	58.0	72.5	87.2	100	116
120	60%	36.4	48.4	60.6	72.8	85	97

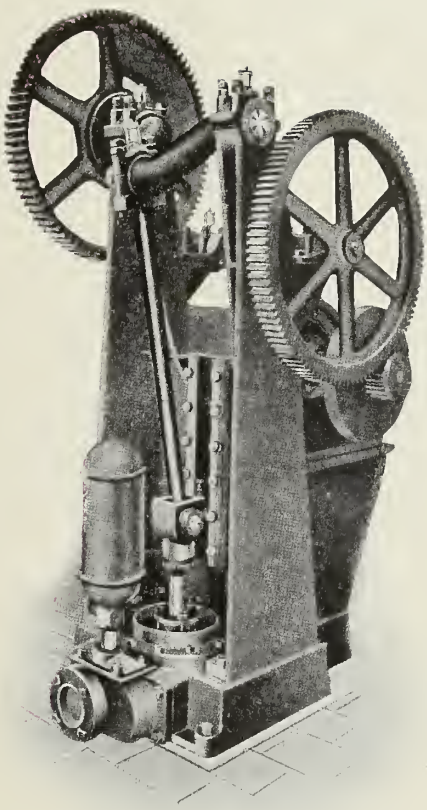


Fig. 3.

(c) AIR LIFT. Until the advent of the air lift, operators were unable to get more than an extremely limited quantity of water from a well of a given diameter and depth, and the perfection and commercializing of the air lift was a great boon to those who possessed wells capable of yielding in excess of the capacities of the direct acting deep well pump, for previous to this time to exceed these capacities they were compelled to provide means of lowering the pumps used to a depth that would permit them to draught the wells or source of supply to the extent of their capacity or the operators' wants.

The air lift however provided a means for getting a much greater quantity of water and this feature, coupled with the simplicity of the well parts, blazed its way to immediate popularity and its only objection is lack of efficiency that has kept it from monopolizing the field of deep well pumping.

As to different types of well devices for air lift purposes many patents have been taken out and much gray matter wasted in attempting to develop something that would produce an economy superior to that produced by the original, or Pohle device, and while patents galore have been granted and with the knowledge that today many are engaged in the manufacture and exploiting of devices for which vast claims are made, the writer has never in his experience and tests made been able to secure results superior to those which he could obtain under similar or like circumstances with the Pohle deep well parts.

Fig. 5. shows a conventional Air Lift pumping equipment.

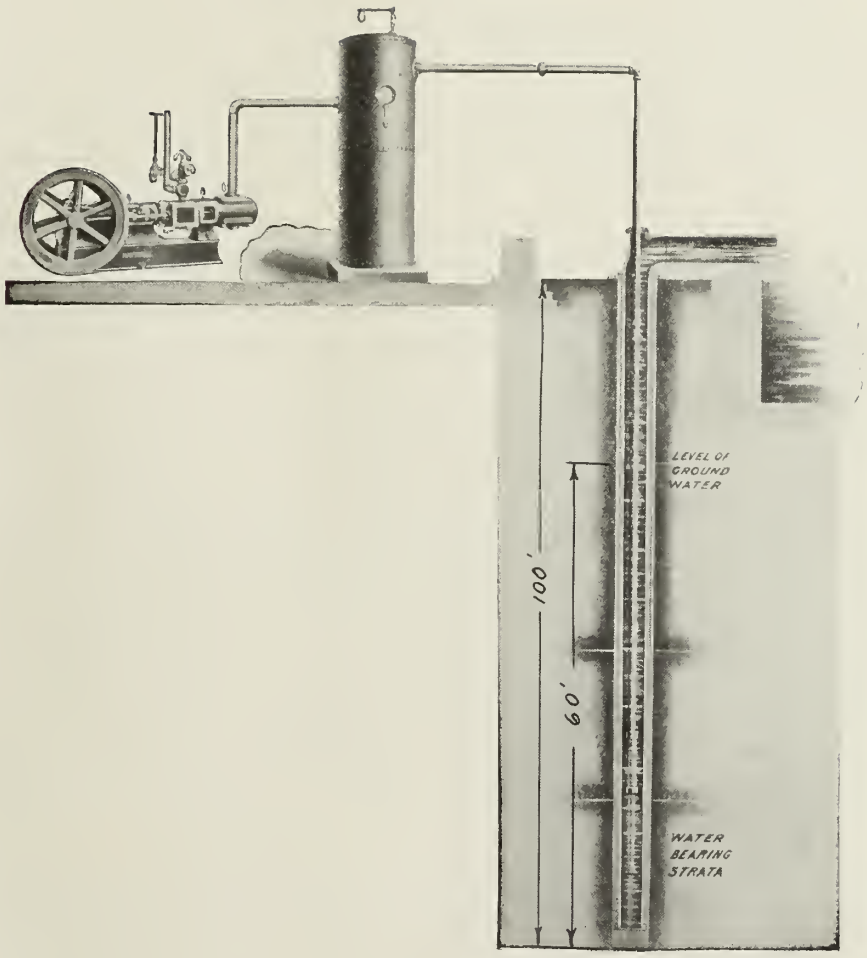


Fig. 4.

In point of efficiency, that is, indicated horse power of compressor compared with the pump horse power of the well output, the best we have been able to produce or find is 20% and this with conditions most favorable as to submersion and the total lift but 30 feet, or from the surface of the water in well as drawn down by draft to the level of the water in the receiving receptacle on the surface.

This efficiency naturally falls off at a very rapid rate with either the increase of the lift or circumstances which prevent the proper submergence being obtained. The economy may therefore in our opinion be based on an efficiency depending on the above items of from 10 to 20% and a steam consumption within the practical range of 15 to 40 pounds per indicated horse power varying of course with the cost and horse power of the compressor unit. The following table gives the author's ideas based on his experience of the results that may be expected from air lift devices:

Steam Consumption of Air Lifts per Pump Horse-power-Hour.

Lift in Feet.	Efficiency in Percent.	Steam Consumption in pounds per I.H.P.-hr. of Steam End of Air Compressor.					
		15	20	25	30	35	40
90	10	150	200	250	300	350	400
60	15	100	133	167	200	234	267
30	20	75	100	125	150	175	200

(d) IMPELLER PUMP. Within the last ten years a vast number of experiments have been made and energy put forth in the development of what is known as the Impeller Pump for extracting water from deep wells. Fig. 5. will give an idea of the mechanical construction of these types. It consists of a vertical shaft on which are at regular intervals, say about six feet apart, located screws or impellers. The water must flow to the lower impeller by gravity when it is thrown upward in the casing in a swirling motion and just before reaching the second impeller is diverted directly upwards and the swirling stopped by a deflecting vane placed immediately below each impeller with the exception of the lower one.

As to durability, this pump possesses many of the same objectionable features attending the direct acting deep well pumps but with the development of a few years the reliability has been greatly improved upon until today it apparently surpasses that of the deep well pump although fails to approach the air lift.

As to efficiency, the writer's whole experience with this type of pump is limited to reading and observation, we find that while numerous tests have been made, in all but the case of one test they appear to have been made by builders, the details of which they seem loath to give out. The ones from which details are available namely those made on the Alvord Pump at the Hydraulic Laboratory of the University of Wisconsin, credits this type with a mechanical efficiency that is horse power of water output compared with brake horse power on vertical shaft of from 30 to 40%. These tests, however, were what might be termed shallow well tests and therefore do not convey to the readers the more reliable information

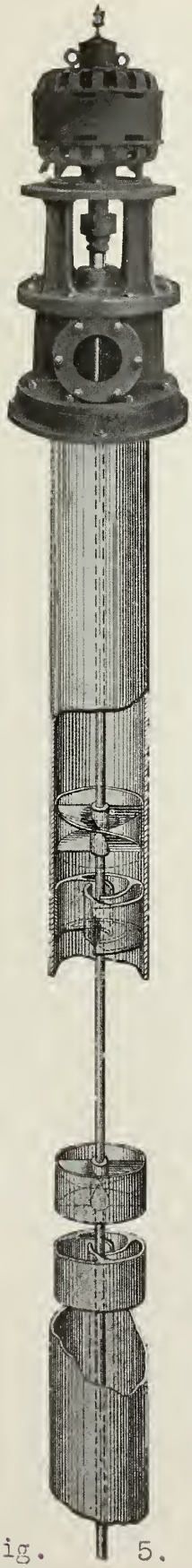


Fig. 5.

they would desire as to the suitability of this machine for drafting deep wells.

Not less than six makers are today putting on the market a machine of this type, most of whom assert their willingness to make guarantees of from 30 to 40% varying with the diameter and depth of the well in which the machines are to operate.

In addition to these efficiencies the economy is of course further effected by the electric generating facilities, and the table below has been prepared as a means of aiding the engineer's judgment in determining what may be expected of the Impeller Pump in the way of economy:

Duty obtainable from Impeller Pumps assuming a transmission efficiency of 80%.

Pump Efficiency.	Steam Consumption of Engine.	
	35 pounds per I.H.P.	25 pounds per I.H.P.
30%	13,550,000	19,000,000
35%	15,800,000	22,100,000
40%	18,100,000	25,300,000

In regard to the quantity that may be extracted from a well, this device excels all others to date, having shown the ability when the water is forthcoming to raise to the surface from almost any depth quantities in excess of all other types including the air lift. The capabilities with different diameters are about as follows:

6" - 300 g.p.m.
7" - 500 g.p.m.
8" - 600 g.p.m.
10" - 1000 g.p.m.
12" - 2400 g.p.m.

We are prone to look upon this type as the coming means of obtaining water from depths greater than suction for general water works practice and hope it will lend encouragement in the development of underground or naturally filtered water supplies and thus supplant or prevent the necessity of installing either a device low in economy or going to the enormous expense that has been incurred at places such as Monmouth, Illinois; Ft. Worth, Texas; New Albany, Indiana; Rockford, Illinois or Memphis, Tennessee, where shafts have been sunk to great depths to permit the water ends of the pumps to be placed within suction distance of the required supply, and which method is illustrated by Fig. 6. which plan was prepared by the writer for a plant near Pittsburg, and while in this plan is incorporated a centrifugal pump, electrically driven, nearly every installation of this kind differs. At Ft. Worth and Rockford the pumps were steam driven through a rope drive transmission; at Monmouth, Illinois, direct acting pumps were placed in the bottom of the pit and power provided by a steam engine through bell cranks and long rods; at Memphis, direct acting high duty pumps were installed, the steam ends driving the water plungers direct through long rods working in guides held in place by structural iron extending from the sides of the pit, and the thrust taken up by intermediate housing.

Fig. 7. is a plan by the author for a Texas town where the water was 100 feet below the surface.

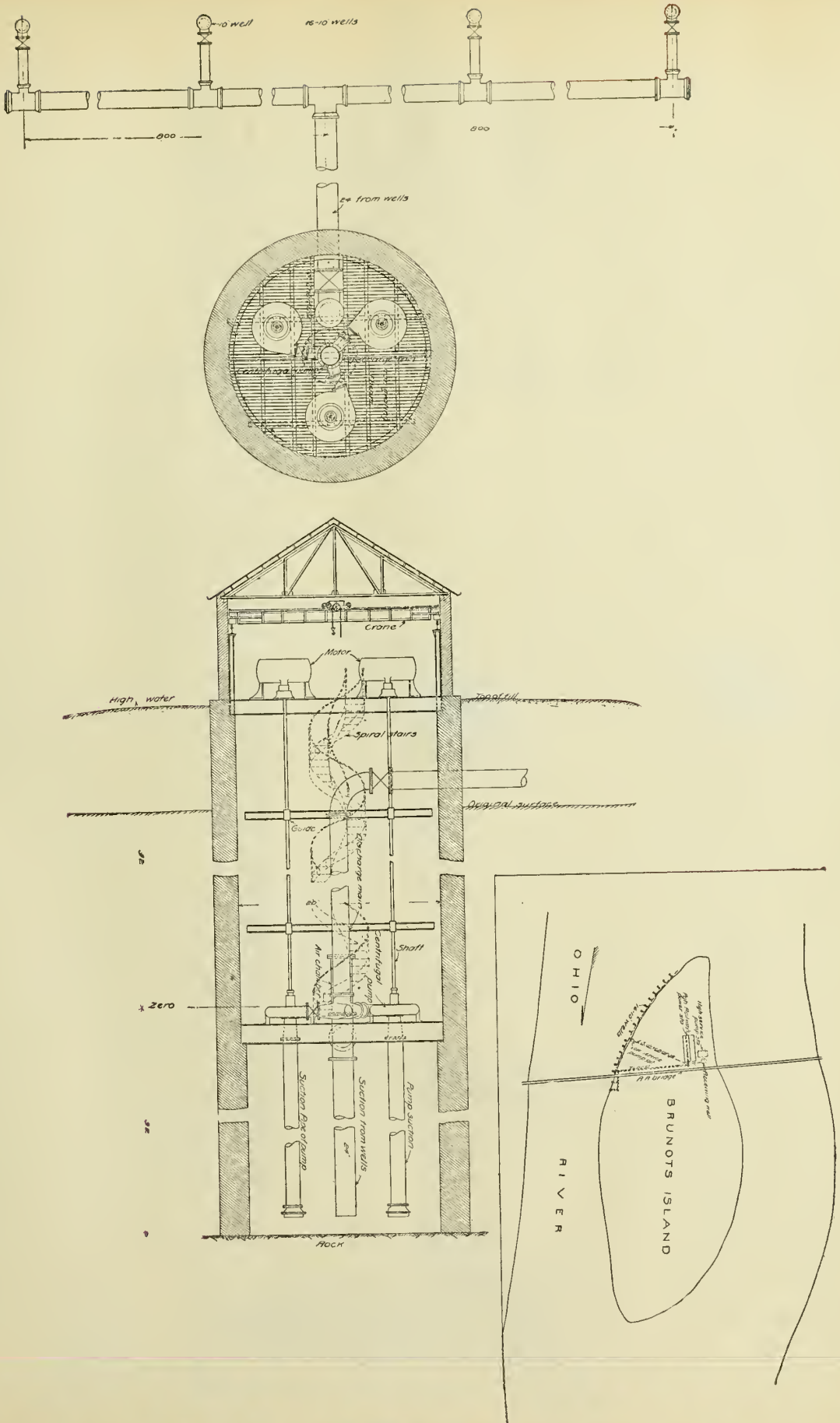

6-0 well
15-10 wells
800
800
Suction from wells
Crane
Motor
High water
Top of fill
Spiral stairs
Original surface
Guide
Discharge main
Shaft
Air chamber
Centrifugal pump
Zero
Suction Pipe of pump
Suction from wells
Pump Suction
Rock
OHIO
RIVER
BRUNOTS ISLAND

Fig. 6.

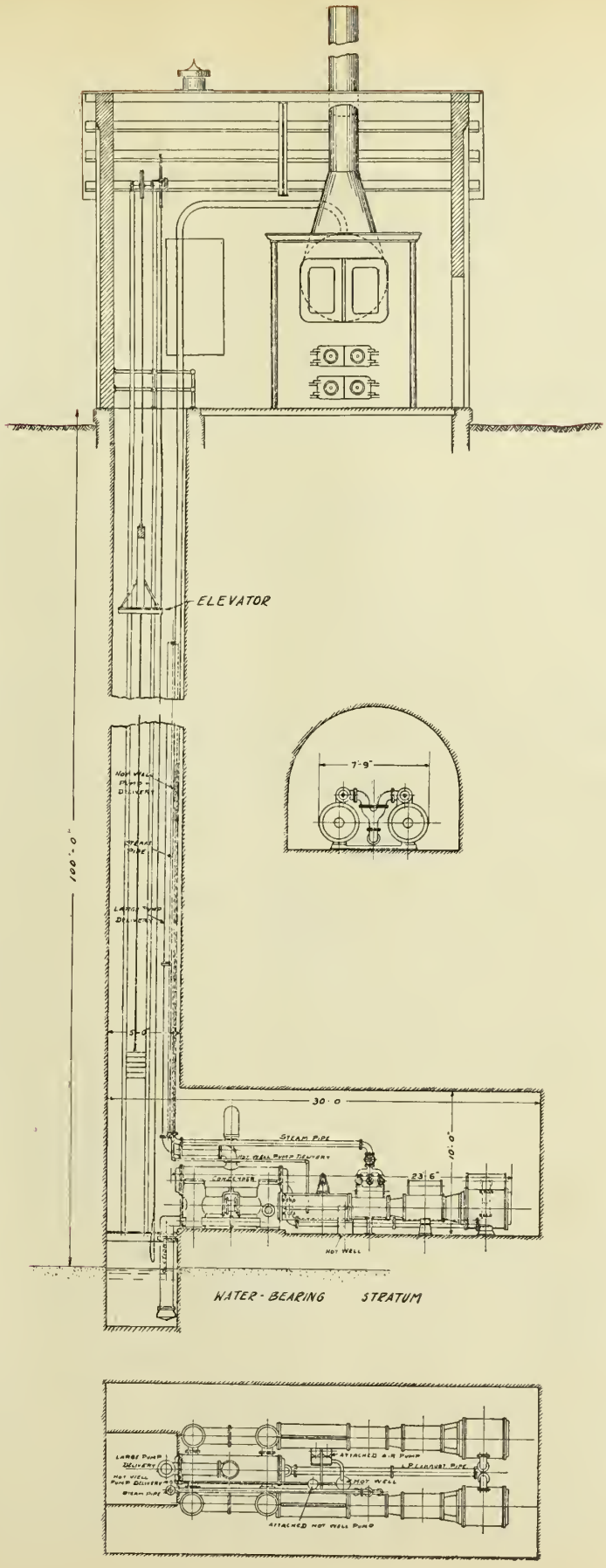

ELEVATOR
7·9"
100·0"
30·0
STEAM PIPE
HOT WELL
WATER-BEARING STRATUM
ATTACHED AIR PUMP
EXHAUST PIPE
ATTACHED HOT WELL PUMP

Fig. 7.

LOW SERVICE PUMPS

The service, the selection of pumps for which at this writing appears to be causing Hydraulic Engineers most concern, is that of the low or to settling or receiving basins and with the universal filtration of all surface supplies, this choice must be made in fifty per cent of all waterworks installations.

It is not that the service is difficult but owing to so little data being available as to the economy that makes this selection a task.

Low service pumps when working against a head of sixty (60) feet or less (and beyond this they should be classed as general service) are almost universally operated in connection with general service pumps and therefore the only records as to economy available are the simple comparisons between different types in connection with other or similar types of general service machines, or duty tests for acceptance of machines which are always higher than can be counted upon in general service, and therefore misleading.

This field until within the last five years was occupied by nearly every type of pump from the duplex simple to the vertical triple expansion crank and fly wheel but within the period named it has practically narrowed down to two types; viz., the direct-acting condensing duplex triple expansion engine and the centrifugal, driven sometimes by what the service dictated and again what the pride or ignorance of the parties making the

selection most desired.

Where the general service is standpipe or direct and no considerable raw or clear water storage is provided between general and low service, the first or direct acting triple expansion alone will be found economical and therefore practical, the centrifugal not being adapted to variations in quantity discharged. Again, along our rivers that rise and fall more than fifteen (15) feet, it becomes necessary in order to place the motor above high water and the pump within suction distance of low water, to install some sort of a vertical machine and here again the direct acting triple is most applicable for the centrifugal is not so susceptible to the separation of the pump and the motive power, although neat installations exist where the transmission is through rope drive or the pump is placed horizontally with the shaft standing vertical and extended to the top of the dry well where it attaches to the motor, and again, the centrifugal is not well adapted to variable lifts, its economy falling off with either increase or decrease of the head for which it was designed.

Notwithstanding the fact that high guarantees have been made and obtained for the centrifugal type and especially when geared to a high speed steam turbine and provided with high vacuum, we have failed to find a single instance where when the comparison could be made that the direct acting triple would not perform the service from month to month at a lower steam and consequent fuel consumption than the centrifugal and as this with the exception of cross compound Corliss engine direct connected to centrifugals is the most economical installation of which we know, we would

ordinarily recommend the installation of the primary unit in the direct-acting triple type with an alternate in the centrifugal direct connected either to a steam turbine or engine. The station duties of these two types will vary with water horse power from 20,000,000 to 50,000,000.

The centrifugal type is most at home and probably to be most seriously considered under the following conditions:

(1) When the total lift is less than 15 feet;

(2) When the ratio of the water horse power of the low to that of the high permits all of the heat of the exhaust steam from the low service motors to be absorbed in the feed water heater through which the boiler supply for the entire plant passes;

(3) When the water to be handled is charged with heavy grit or foreign substances that will cause excessive cutting in the valves and plungers of a reciprocating machine;

(4) When the capacity of the units, the service being properly proportioned out, must exceed 10,000,000 gallons and the total service is in excess of 20,000,000 gallons per day.

The filters of the city of Pittsburg are supplied from the Allegheny River, the pumpage being between 75,000,000 and 100,000,000 gallons per day the head varying from 40 to 50 feet with enormous centrifugal units to which the water flows by gravity and which are driven by direct-acting vertical cross compound Corliss condensing engines, and the duty varies from 40,000,000 to 49,000,000 per 100 pounds of coal consumed at this station, and while in the installation it was hoped to keep down the repairs

this feature has unfortunately been a serious burden. However considering the quantity and quality of water to be handled, we feel that the type selected is in this case better than the reciprocating machine.

GENERAL SERVICE

Before any selection is attempted or specification drawn, the Engineer should decide whether unit should be vertical or horizontal, and should then narrow the consideration down to not more than two of the following types:

Triple expansion, Crank and Fly-wheel;

Cross compound, Crank & Fly-wheel;

Direct-acting Triple expansion, Duplex;

Direct-acting Compound, Duplex.

As to whether an engine should be horizontal or vertical in as much as within reasonable limits the first cost and the accessibility of the horizontal makes it the more desirable engine, We believe that engines should be of this class except first, whenever they are to take their suction from a river that rises and falls more than 15 feet or from driven wells or subterranean supplies in which said supply when being drafted to maximum draws down in excess of 20 feet below ground level, and

Second, whenever the conditions as to capacity, steam pressure, and water horse power make$ the moving parts sufficiently heavy that in the horizontal engine the drag and consequent wear of the pistons and plungers will involve an operating expense in the way of loss by friction and up-keep greater than the fixed charges arising from the excess cost of a vertical over the horizontal, housing, foundations and all considered.

The direct-acting engine when properly designed and constructed will operate equally well in a vertical or horizontal

position. The crank and fly wheel engine however is generally conceded to be at its best in the vertical.

The two elements that most effect economy are speed and expansion. The greater number of expansions within limit provides the greater economy; however, high rate of expansion calls for an enormous exposure of cylindrical surface and consequent high cylinder or jacket condensation and loss. The ratio of this loss varying almost directly as the piston speed, it may therefore be readily seen why a high class engine loses more rapidly in economy when working under its rated speed than a lower class, and in this respect we are pleased to quote from the Proceedings of the Illinois Society of Civil Engineers in a paper by H.M.Ely, C.R.Henderson, and C.G.Cobb, (from which we have drawn otherwise) the following:

> "One pumping station equipped with low duty, direct acting pumps but operated at the best speed for economical steam consumption may show greater economy than another station equipped with high grade crank and fly wheel machines operating at poor speeds for economical steam consumption".

This assertion has been more than borne out by our experience and the records we have be n able to keep.

Notwithstanding this pertinent fact, however, a large per cent of the installations of pumping machinery within the last ten years have been monuments to the ignorance of purchasers of pumping machinery in this respect or being wise to this fact, they have let their pride or desire for something showy overcome their better judgment and installed machines of both higher class and

capacity than the conditions warranted.

Depreciation and repair varies principally with two factors. First, the number of moving and working parts, and second, the number of reciprocations, revolutions, or reversions.

The above assumes of course the proper design and construction which we regret to say is not found in too large a per cent of existing machines and in fact it may be truthfully claimed that over 50% of the gross repair account of water works engines in this country are chargeable to poor design or workmanship. Happily, however, over 50% of the gross probably emanates from less than 20% of the total pumping stations.

A factor contributing to the economy or lack of economy in engines is the type of water end, whether plunger and ring or outside packed. While we do not advocate the former type for engines in excess of five million gallons or pressures of over 100 pounds yet within this range for filtered water (and general service pumps should handle nothing but filtered water or its equivalent) the plunger and ring type is lower of first cost and will contribute 5% to the economy of operation and the up-keep, for the same per cent of slippage should be no more than of the outside packed type for the turning down of the plungers and occasional renewing of the lining of the ring will cost no more than the packing for the type that demands it.

Manufacturers of pumping machinery never, and operators either don't appreciate or they stubbornly refuse to consider the fact that few engines in their actual operation are permitted to deliver nearly their annual capacity due on all services to the

necessity of every engine being shut down for repair and overhauling from 10 to 25% of the time varying generally with the severity of the service and on direct or standpipe service to the fact that the speed and consequent delivery can only equal the consumption which frequently varies from 25% of the capacity of the machine between 2 and 4 in the morning to full or overcapacity from 4 to 6 in the afternoon.

To ascertain the actual conditions in this respect the writer recently tabulated data covering one year's operation from thirty-eight different stations containing 130 different engines, wherein we first classified the stations into reservoir and direct or standpipe. We also classified the machines into primary and alternate units, for in all but few stations where the daily draft is five million or less, there is always one machine more economical than the other and is consequently called upon to do the major portion of the work. The following are the average results of these tabulations:

		Per cent time in Operation.	Per cent Annual capacity delivered.
Primary Machine	on Direct or Standpipe Service	85.7	44.7
Alternate "	on Direct or Standpipe Service	10.4	7.9
Primary "	Reservoir Service	77.4	65.5
Alternate "	Reservoir Service	8.5	6.7

As in manner of operating so it is in economy, there has been an absolute refusal on the part of pump builders and the

failure on the part of many purchasers to recognize the fact that the annual station duty must necessarily be but a limited percentage of a builder's guarantee arising from the following facts:

(1) Builders' guarantees are generally abnormally high, obtained only by experts under exact contract conditions as to head, steam pressure, and capacity, and

(2) From the fact that few machines operate any appreciable per cent of their time under contract conditions and are subject to losses beyond the control of either the builder or the operator.

To form a basis of what may be expected in the way of station duties, we have collected and tabulated the following data pertaining to station results which standing alone appear contradictory, for the high duties in Class (C) are higher than those in Class (B), abnormal duties appearing to have been obtained at South Pittsburg and Butler. At South Pittsburg this can be attributed to super heated steam units when at work operating at nearly their maximum capacity and care taken to prevent losses by radiation.

At Butler, to natural gas of high thermal value and the unit being worked beyond its rated capacity.

In the Class (A) engines listed for Chicago and Pittsburg we believe the results obtained about equivalent when due allowance is made for the difference in the thermal value of the coal.

CLASS A STATIONS.

Plant.	Gallons Pumped.	Head Ft.	H.P.	Lbs. of Coal or Gas Equiv.	Duty per 100 lb. Coal	Lbs. Coal per hr. per H.P	Cost Coal Ton.	Cost of Fuel.	Cost of Oil.	Cost of P. & W.	Engrs. Salary.	Cost Coal per M.G. per year.	Cost Oil per H.P.	Cost P. & W. per H.P.	Engrs. Sal. per H.P.	Total Cost per H.P.
Pgh.,Brilliant Sta.1.	13,987,[illegible],900	360	2480	49,512,180	27,000,000	2.26	1.35	33,441.35		34,140.52		13.48		13.76		27.24
Pgh.,Howard Station	1,023,002,401	361	334	6,696,380	28,500,000	2.39	1.39	4,667.24		11,311.86		13.00		34,00		47.96
Detroit,Michigan	27,816,750,890	132.5	1772	36,066,844	29,100,000	2.33	2.55	45,975.84	872.07	436.74	1,313.83	24.78	.49	.25	23.30	48.82
Pgh.,Brilliant Sta.2.	2,767,539,170	280	1960	43,735,820	27,300,000	2.35	1.35	29,639.66		29,729.64		15.12		15.15		30.27
Pgh.,Herron Hill Sta.	1,354,008,720	143	450	10,480,000	74,600,000	2.66		15,712.92		13,064.71		9.00		29.00		64.00
Chicago,14th St.Sta.	25,026,404,763	115.2	1565	36,400,000	29,624,000	2.84	2.75	50,000.00		26,900.00	37,650.00	32.00		17.14	24.00	73.14
Jamestown,New York	1,120,637,200	224	121	3,036,390	69,000,000	3.87	2.78	4,220.60		739.45	6,556.83	34.65		3.33	29.50	67.48
Harrisburg,Pennsylvania	3,803,839,700	235	430	11,994,858	65,134,042	3.0	1.25	6,700.00		632.42	7,257.38	15.55		1.47	16.08	33.90
Chicago:																
Chicago Ave.Sta.	21,118,497,789	115.6	1126	36,800,000	64,017,000	3.09	2.64	48,300.00		25,150.00	47,700.00	43.15		22.38	42.40	107.93
Central Park Ave.Sta.	18,544,221,811	115.3	1348	28,700,000	63,900,000	3.10	2.46	35,230.00		19,470.00	34,300.00	26.35		14.42	23.42	67.19
Springfield Ave.Sta.	18,785,473,508	115.1	1232	26,900,000	61,650,000	3.21	2.32	31,200.00		14,450.00	29,850.00	25.30		11.72	23.10	60.12
Harrison St.Sta.	11,518,485,798	105.7	625	16,700,000	57,850,000	3.41	2.47	20,630.00		10,150.00	24,800.00	33.10		25.82	39.70	98.82
Pgh.,Montrose Sta.	12,081,752,350	219.5	1272	40,379,200	54,700,000	3.32	1.33	26,729.90		45,631.48		21.00		35.80		56.80
Racine,Wisconsin	748,890,800	195	71.57	3,409,061	50,500,000	3.8	2.56	3,087.87	77.38	68.04	3,179.80	43.14	1.08	.95	44.43	89.60
Terre Haute,Illinois		172	132													
		68														

CLASS B STATIONS.

Jamestown,New York	1,034,488,030	203	101	2,856,334	61,500,000	3.26	2.43	3,470.43								
Meadville,Pennsylvania	501,402,456	301	72.5	2,100,000	60,000,000	3.3	2.16	2,272.07	142.78	165.53	3,355.00	31.35	1.97	2.38	46.30	81.90
Sheboygan,Wisconsin	1,003,263,800	176	86.53	2,887,628	50,500,000	3.8	3.10	4,475.26	42.69	25.00	3,230.34	31.72	.49	.29	37.33	80.83
New Castle,Pa.	1,064,420,000	309	188.05	6,622,800	52,000,000	4.0	2.05	6,800.06	165.90	79.06	3,371.21	36.16	.88	.42	17.93	55.39
	120,871,000	455														
Chicago,38th St.Sta.	24,566,460,540	124.9	1658	49,000,000	49,596,000	3.99	2.37	58,200.00		25,500.00	48,400.00	35.15		15.40	29.20	79.75
Chattanooga,Tennessee	1,571,377,600	268	206.36	7,205,350	44,000,000	4.0	1.93	6,944.44	158.89	137.01	4,483.96	33.65	.77	.66	21.75	56.81
Chicago,22nd St.Sta.	18,274,736,800	99.9	902	32,300,000	47,990,000	4.14	2.60	42,000.00		16,120.00	36,750.00	46.52		17.90	40.70	105.12
Chicago,Lake View	11,826,008,773	105.3	598	18,470,000	46,750,000	4.25	2.87	26,300.00		12,780.00	30,900.00	44.30		21.35	51.60	117.25
Little Rock,Arkansas	1,288,793,000	313	197.70	7,978,600	42,000,000	4.6	2.14	8,544.52	418.88	417.42	3,906.82	43.22	2.12	2.11	18.76	67.21
Peoria,Illinois		310	312		38,333,000	5.31										
Joplin,Fire Sta.	848,780,700	98	39.90	2,374,840	25,500,000	8.8	1.90	2,258.83	63.12	24.78	2,259.15	56.61	1.58	.62	56.62	115.43
Danville,Illinois		230	122		28,637,300	7.34										
		14														
Rock Island,Ill.		230	122		25,036,000	7.90										
Elgin,Illinois		173	65		21,789,200	9.08										

CLASS C STATIONS.

Plant.	Gallons Pumped.	Head Ft.	H.P.	Lbs. Coal or Gas Equivalent.	Duty per 100 lb. Coal	Lbs. Coal hr. pr. H.P.	Cost Coal Ton.	Cost of Fuel.	Cost of Oil.	Cost of P. & W.	Engineers Salary.	Cost Coal per H.P. per year.	Cost Oil per H.P.	Cost P. & W. per H.P.	Engrs. Sal. per H.P.	Total Cost per H.P.
S.Pittsburg, Pa.	2,534,543,000	410	500	11,188,361	77,000,000	2.52	1.40	7,820.98	483.26	48.58	7,742.10	15.62	0.97	.097	15.45	32.14
Butler, Pa.	858,297,700	285	119.88	2,857,480	71,000,000	2.7	1.95	2,791.71	105.90	49.95	2,196.00	23.29	0.88	0.42	18.32	42.91
Wichita, Kansas	1,207,167,600	165	97.61	3,308,165	51,000,000	3.7	3.20	5,288.21	88.32	38.53	2,632.76	54.16	0.90	0.50	26.97	82.39
Birmingham, Ala., Cahaba	2,389,100,000	416	487.10	16,522,900	50,000,000	3.8	1.20	9,793.74	197.74	241.16	6,890.38	20.10	0.41	0.49	14.13	35.13
Joplin, Missouri	883,965,400	230	99.63	3,565,065	47,500,000	4.1	1.72	3,067.58	62.61	32.19	1,316.14	30.79	0.63	0.32	13.21	44.95
Shreveport, Louisiana	960,560,170	275	129.45	4,907,126	45,000,000	4.3	2.40	6,035.23	238.32	34.06	3,386.68	46.62	1.84	0.26	36.16	74.88
St. Joseph, Missouri	2,029,488,800	370	367.99	16,500,000	37,500,000	5.1	2.68	22,092.65	263.25	192.37	7,775.75	60.04	0.71	0.52	21.13	82.40
Pgh., S. 28th St. Sta.	1,539,432,068	486	360	16,430,000	37,500,000	5.22	1.43	11,731.14		12,774.30		32.65		35.50		68.15
Birmingham, Ala., North	858,141,500	230	96.71	4,540,850	36,000,000	5.3	1.45	3,288.09	87.52	42.94	3,661.97	34.00	0.91	0.45	37.87	73.23
Connellsville, Pa.	552,627,000	326	88.28	4,443,238	34,000,000	5.7	1.52	3,381.66	99.21	61.38	2,294.00	38.31	1.12	0.69	25.99	66.11
Elizabeth, Pennsylvania	443,398,800	334	72.58	4,094,658	30,000,000	6.5	1.35	2,763.88	87.12	55.84	3,224.00	38.08	1.20	0.77	44.42	84.47
Sioux Falls, South Dakota	373,328,000	179	32.75	1,939,345	28,700,000	6.7	4.66	4,518.81	129.94	167.26	1,850.10	137.98	3.97	5.11	56.49	203.55
Purdue, Indiana	794,065,800	135	52.53	3,305,400	26,000,000	7.2	2.30	3,795.24	51.09	48.30	2,699.49	72.25	0.97	0.93	51.39	125.54
Mt. Vernon, Indiana	312,382,100	275	39.04	2,403,000	26,000,000	7.2	1.06	1,301.39	152.09	84.44	1,036.18	33.34	3.90	2.16	27.31	66.71
East St. Louis,	2,802,430,300	165	263.60	15,629,000	24,000,000	7.8	1.93	15,062.02	397.22	255.40	6,255.00	66.47	1.75	1.13	27.60	96.95
Freeport, Pennsylvania		199	44		24,210,457	8.17										
Clinton, Iowa	574,660,200	138	38.86	2,728,566	24,200,000	8.00	1.88	2,567.94	79.56	61.88	2,637.30	66.08	2.05	1.59	67.86	137.58
Granite City, Illinois	675,344,600	210	69.50	6,044,581	19,600,000	9.9	1.97	5,972.92	202.60	84.03	3,598.20	85.94	2.92	1.21	51.77	141.85
Waukegan, Illinois		120	65		18,114,480	10.96										
Keokuk, Iowa	292,521,600	236	33.83	3,223,000	17,800,000	10.8	1.78	2,860.44	34.73	32.90	2,816.51	84.58	1.03	0.97	83.28	169.84
Streator, Illinois		100	46		14,669.130	13.6										
		65										192.68	9.62	1.00	168.15	371.45
Argenta, Arkansas,	127,625,100	127	7.94	1,101,400	13,400,000	15.8	2.78	1,529.87	76.39	7.95	1,335.08					
Decatur, Illinois		90	71		10,133,100	19.5										
		45														

CLASS D STATIONS.

Marinette, Wisconsin	684,452,500	167	56.02	2,894,530	32,900,000	5.9	2.93	4,233.64	153.18	31.34	2,765.75	75.57	2.04	0.56	49.19	128.26
Huntington, W.Va.	792,736,600	355	137.91	7,211,200	32,400,000	6.0	1.82	6,574.65	104.09	61.89	2,334.24	47.67	0.75	0.45	16.93	65.80
Pgh., Garfield Station	350,370,000	200	33.7	1,932,000	30,200,000	6.55		2,895.45		2,590.18		86.00		77.00		163.00
Pgh., Lincoln Station	195,380,000	310	290	1,700,000	29,600,000	6.7		2,546.55		2,703.30		88.00		93.25		181.25
New Philadelphia, Ohio	224,023,990	317	34.80	2,313,700	25,600,000	7.6	1.28	1,477.62	36.74	24.01	888.65	42.46	1.06	0.69	25.53	69.74
Louisiana, Missouri	177,855,310	340	29.63	2,045,300	24,600,000	7.8	2.14	2,185.45	29.56	29.86	773.05	73.76	0.99	1.01	26.09	101.85
Quincy, Illinois		220	233		22,903,975	8.6										
		64										91.63	1.82	0.49	62.06	156.00
Warren, Pennsylvania	382,925,500	125	23.46	1,761,560	22,400,000	8.7	2.41	2,149.74	42.78	11.65	1,456.00	98.45	1.68	4.22	65.16	169.51
Meridian, Mississippi	405,058,200	150	29.77	2,320,460	21,800,000	8.9	2.53	2,930.94	50.13	125.60	1,939.82	116.50		32.70		149.20
Pgh., Hill Station	79,524,602	550	21.0	1,956,500	18,700,000	10.6	2.50	2,445.54		686.54		84.00		184.00		268.00
Pgh., Troy Hill Station	385,805,240	181	33.5	3,953,420	14,400,000	13.7	1.42	2,816.41		6,182.29		138.56	1.73	0.65	49.30	190.24
Kokomo, Indiana	530.415,246	135	35.09	4,555,270	13,000,000	14.8	2.13	4,862.21	60.57	22.75	1,730.06					
Oak Park, Illinois		82			6,903,000	28.7										
		175	46													

From the operating records of a large number of private plants open to us, we have found that the following salaries are the average paid to engineers in charge of the different classes of stations:

Class (A) First engineer $110. per month; second engineer $90. per month;

Class (B) First engineer $90. per month; second engineer $75. per month;

Class (C) First engineer $75. per month; second engineer $60. per month;

Class (D) First engineer $60. per month; second engineer $50. per month.

For their daily capacity, viz., five million gallons and the demand varying from three to five million gallons, from the tabulated records of performances, we have deduced that on reservoir service we can obtain station duties as follows:

Class (A) 75,000,000

Class (B) 60,000,000

Class (C) 55,000,000

Class (D) 40,000,000

and for direct or standpipe service:

Class (A) 60,000,000 ft. lbs.

Class (B) 45,000,000 ft. lbs.

Class (C) 40,000,000 ft. lbs.

Class (D) 30,000,000 ft. lbs.

and from these duties we have computed the annual coal consumption basing the time of operation upon the results given in the tabulation on page 23.

On reservoir service since domestic and fire pressure are generally provided by the reservoir head and are one and the same, we have made an allowance for extra boiler capacity for the lower classes of machinery, but with direct service since it becomes necessary on a triple expansion crank and fly wheel engine to bleed steam beyond the cut-offs of the high pressure cylinders or into the receiver between the high and the intermediate, and where cross compound is used, into the receiver between the high and low, and where the direct-acting triple is used, into the intermediate cylinders; thus putting all for fire service nearly at par so far as economy is concerned, and requiring sufficient boilers to be kept in commission at all times to provide for the maximum service at the minimum economy; any allowance for additional cost of extra boilers on any of the lower types is precluded.

TABLE Nº 1.

COMPARATIVE COST OF OPERATION

RESERVOIR SERVICE

5 MILLION GALLONS 240 FEET HEAD 210 W.H.P.

TYPE	DESCRIPTION OF ENGINE	PRICE OF ENGINE	GUARANTEED STEAM DUTY	ADDITIONAL COST FOR EXTRA BOILERS AT $23.00 PER H.P	FIXED CHARGE AT 10%	ANNUAL DUTY PER 100 LB. COAL UNDER AVERAGE CONDITIONS	ANNUAL COAL CONSUMPTION TONS
A	TRIPLE EXP., FLY-WHEEL TYPE	$30000	140 MILLION		$3000	75 MILLION FT-LB	2428
B	CROSS COMPOUND, FLY WHEEL	17000	120 "	$380	1738	60 " " "	3035
C	TRIPLE EXP., DUPLEX, DIRECT ACTING	12000	95 "	1085	1308	55 " " "	3311
D	COMPOUND, DIRECT ACTING	10000	65 "	2470	1247	40 " " "	4553

ANNUAL OPERATING COST

PRICE OF COAL PER TON	TYPE OF ENGINE	FIXED CHARGE AT 10%	COST OF COAL	ENGINEERS' SALARY	TOTAL COST
$1.00	A	$3000	$1518	$2400	$6918
	B	1738	2024	2000	5762
	C	1308	2277	1600	**5185**
	D	1247	3035	1400	5682
1.50	A	3000	2276	2400	7676
	B	1738	3036	2000	6774
	C	1308	3415	1600	**6323**
	D	1247	4553	1400	7200
2.00	A	3000	3035	2400	8435
	B	1738	4047	2000	7785
	C	1308	4553	1600	**7461**
	D	1247	6070	1400	8717
2.50	A	3000	3794	2400	9194
	B	1738	5059	2000	8797
	C	1308	5691	1600	**8599**
	D	1247	7588	1400	10235
3.00	A	3000	4553	2400	9953
	B	1738	6071	2000	9809
	C	1308	6830	1600	**9738**
	D	1247	9105	1400	11752
3.50	A	3000	5312	2400	10712
	B	1738	7083	2000	**10812**
	C	1308	7968	1600	10876
	D	1247	10623	1400	13270
4.00	**A**	3000	6070	2400	**11470**
	B	1738	8094	2000	11832
	C	1308	9106	1600	12014
	D	1247	12140	1400	14787
4.50	**A**	3000	6829	2400	**12229**
	B	1738	9106	2000	12844
	C	1308	10244	1600	13152
	D	1247	13658	1400	16305

TABLE No 2

COMPARATIVE COST OF OPERATION

DIRECT SERVICE

5 MILLION GALLONS 240 FEET HEAD 210 W.H.P.

TYPE	DESCRIPTION OF ENGINE	PRICE OF ENGINE	GUARANTEED STEAM DUTY	ADDITIONAL COST FOR EXTRA BOILERS AT $23.00 PER H.P.	FIXED CHARGE AT 10%	ANNUAL DUTY PER 100 LB. COAL UNDER AVERAGE CONDITIONS	ANNUAL COAL CONSUMPTION TONS
A	TRIPLE EXP., FLY-WHEEL TYPE	$30000	140 Million		$3000	60 Million Ft-Lb.	3035
B	CROSS COMPOUND, FLY WHEEL	17000	120 "		1700	45 " " "	4047
C	TRIPLE EXP., DUPLEX, DIRECT ACTING	12000	95 "		1200	40 " " "	4553
D	COMPOUND, DIRECT ACTING	10000	65 "		1000	30 " " "	6070

ANNUAL OPERATING COST

PRICE OF COAL PER TON	TYPE OF ENGINE	FIXED CHARGE AT 10%	COST OF COAL	ENGINEERS' SALARY	TOTAL COST
$1.00	A	$3000	$1821	$2400	$ 7221
	B	1700	2276	2000	5976
	C	1200	2483	1600	**5283**
	D	1000	3415	1400	5815
1.50	A	3000	2731	2400	8131
	B	1700	3411	2000	7111
	C	1200	3724	1600	**6524**
	D	1000	5122	1400	7522
2.00	A	3000	3642	2400	9042
	B	1700	4552	2000	8252
	C	1200	4966	1600	**7766**
	D	1000	6830	1400	9230
2.50	A	3000	4552	2400	9942
	B	1700	5690	2000	9390
	C	1200	6207	1600	**9007**
	D	1000	8537	1400	10937
3.00	A	3000	5463	2400	10863
	B	1700	6828	2000	10528
	C	1200	7449	1600	**10249**
	D	1000	10245	1400	12645
3.50	A	3000	6373	2400	11773
	B	1700	7966	2000	11666
	C	1200	8690	1600	**11490**
	D	1000	11952	1400	14352
4.00	**A**	3000	7284	2400	**12684**
	B	1700	9104	2000	12804
	C	1200	9932	1600	12732
	D	1000	13660	1400	16060
4.50	**A**	3000	8194	2400	**13594**
	B	1700	10242	2000	13942
	C	1200	11173	1600	13973
	D	1000	15367	1400	17767

The reader in perusing Tables Nos. 1. and 2. finds that the results or total costs vary with every element in their make-up and while these elements are only approximate they are the product of our best judgment based on average market quotations.

The recent depression has however tended to bring the price of the cross compound fly wheel machine nearer to that of the direct acting triple used here. It has also materially lowered the cost of the compound direct acting machine.

In connection with this last machine, the figures herein based on a five million unit as they are put this type out of its element, for in the light of the present development it should never be employed to the extent of this capacity or water horse power, its field being confined to two million gallon or less where the total head is 240 feet or less and it has been included here more as a matter of comparison and in order to complete the tables and it must further not be overlooked that in stations where the Class (D) or compound direct acting machinery becomes practical that the fixed charges of a higher class would probably preclude its use. In fact, the fixing of a certain capacity is fair to not more than two classes and in this case it is Class (B) and (C) for as the water horse power increases the field is more nearly usurped by the more refined or economical classes and as it decreases, by the more extravagant or less economical classes.

BOOSTER, OR HIGHER THAN GENERAL SERVICE.

Where the quantity to be raised exceeds a million gallons against one hundred pounds pressure or say fifty pump horse power, it is pretty safe to conclude that a steam plant may be considered. Below this, however, the field is contested by two types; namely, gas or gasoline engine driven power pumps and electrically driven centrifugal pumps.

Where natural gas is available the gas engine driven power pump performs the service at a very low fuel cost but it is the disadvantage of a high fixed charge, a high repair account, requires more attention than a centrifugal and a much larger packing and waste account.

The adaptability of the centrifugal pump again depends largely upon the price at which electric current may be obtained and with any price below 5¢ per kilowatt hour it will generally win out against the gas or gasoline driven power pump within the limits of capacity and water horse power given above.

The conditions however of this service are varied. It is generally intermittent; that is, the unit is operated but a few hours per day and often such attendance as it requires may be supplied from some other department and thereby necessitating the labor charge of actual time only, but where remote from the plant the labor charge becomes high.

The same arguments may be presented against the electrical unit but with devices such as the Cutler-Hammer Automatic Starter and Stopper, the attendance required by this type is cut down to an

absolute minimum.

The following are annual results obtained at two plants one a gasoline engine driven power pump supplying Hill City, a suburb of Chattanooga, Tenn., and the other an electrically driven power pump supplying a higher portion of Donora, Pa., where the current was purchased on provision that it be used only after 10 P.M. and 5 A.M. @ 1½¢ per kilowatt:

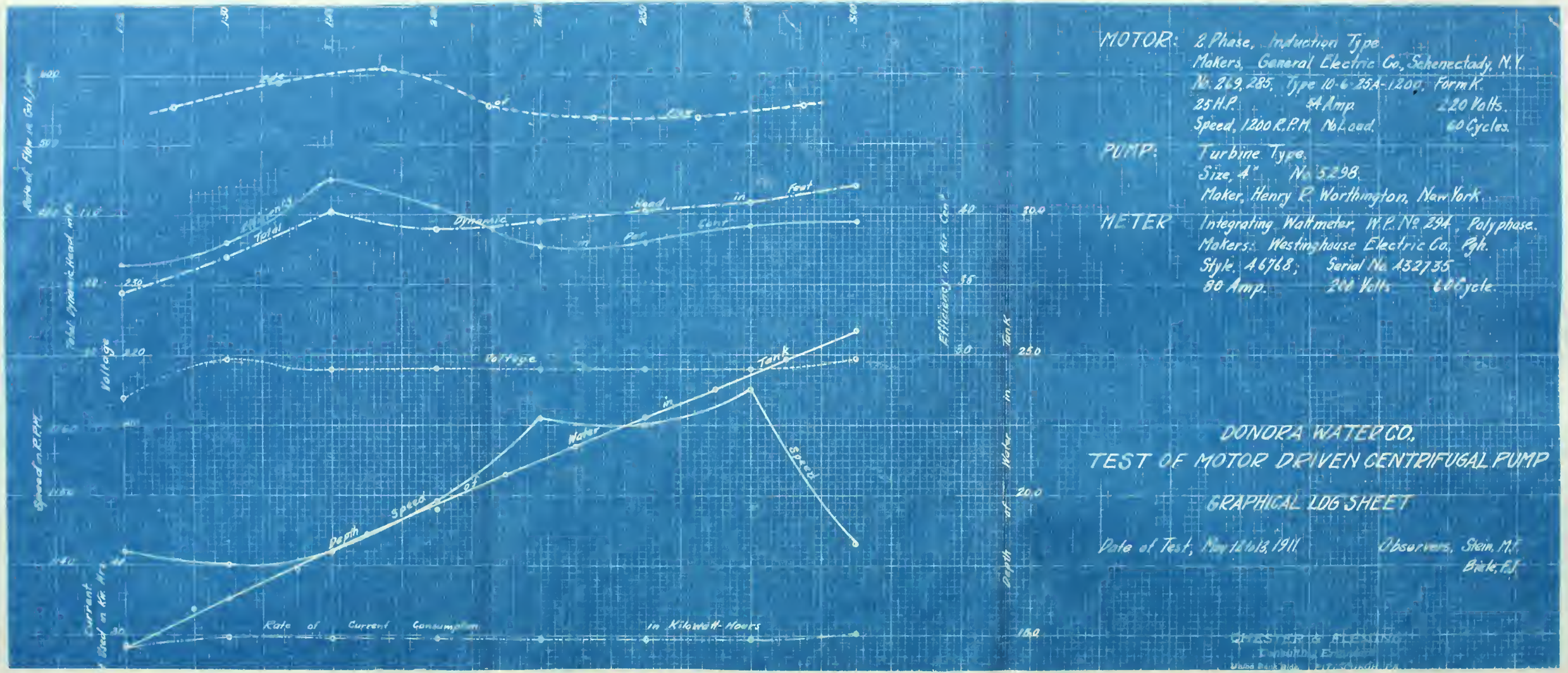
Plant	Gal. pumped Annually.	Power	Total Cost	Cost per Million.	Cost per Million 100 ft. high.
Hill City	11,131,700	$233.	$520.	$46.65	$25.40
Donora	20,000,000	350.	415.	20.75	18.80

In the above tabulation the item of repairs and fixed charges is omitted, therefore the table is not complete but this item will weigh heavily against the gasoline engine driven power pump.

In addition to the data given above a diagram of one performance of the electrically driven pump at Donora which covers the pumpage for one 24-hour period may prove of interest.

In conclusion, no hard and fast rule can be fixed for the selection of a pumping engine. Tabulated and computed results can only assist in moulding the opinion. Actual conditions and trained judgment alone can dictate and this latter is obtained only by contact with actual conditions.

MO
PU
30.0
ME
25.0
TES
20.0
Date
Depth
15.0



MOTOR: 2 Phase, Induction Type.
Makers, General Electric Co, Schenectady, N.Y.
No. 269,285. Type 10-6-25A-1200. Form K.
25 H.P. 84 Amp. 220 Volts.
Speed, 1200 R.P.M. No Load. 60 Cycles.

PUMP: Turbine Type.
Size, 4" No. 5298.
Maker, Henry R. Worthington, New York.

METER Integrating Wattmeter, W.P. No. 294, Polyphase.
Makers: Westinghouse Electric Co, Pgh.
Style. A6768, Serial No. 1327135
80 Amp. 200 Volts 60 cycle.

DONORA WATER CO.
TEST OF MOTOR DRIVEN CENTRIFUGAL PUMP
GRAPHICAL LOG SHEET

Date of Test, May 12 to 13, 1911. Observers, Stein, M.F.
Burke, F.J.

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